Understanding 'Fighting Modulation,' And a DXing Challenge

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"Major Armstrong purchased land atop 500-foot Englewood Cliffs overlooking the Hudson River. There he would build a new FM field laboratory"

It was some 80 years ago when inventor Major Edwin H. Armstrong first experimented with frequency modulation of radio signals. However it took another 40 years before FM radio would begin to gain popular acceptance over AM.

For one thing, the circuitry was inordinately complex compared to AM. Then the reassignment of the FM broadcast band from 42 to 50 MHz to the current 88 to 108 MHz made early receivers obsolete. Perhaps more importantly, the early development of FM was stunted by parallel experimentation with television in addition to competition with AM.

Why invest additional time and money into FM when AM radio was doing well enough and the prospect of television held so much promise? Maybe FM should stand for *Fighting Modulation* because it was such a time-consuming and grueling battle to get to where it is today.

Fractured History of FM

In 1933, Armstrong began conducting FM experiments in the RCA labs at the top of the Empire State Building, the highest point in New York City. At the same time it was becoming clear to Armstrong that fellow experimenter David Sarnoff and corporate sponsor RCA weren't really interested in FM. They wanted to invest in the development of television, and RCA believed FM was a threat to its AM radio business.

Sure enough, in 1935 Armstrong was evicted

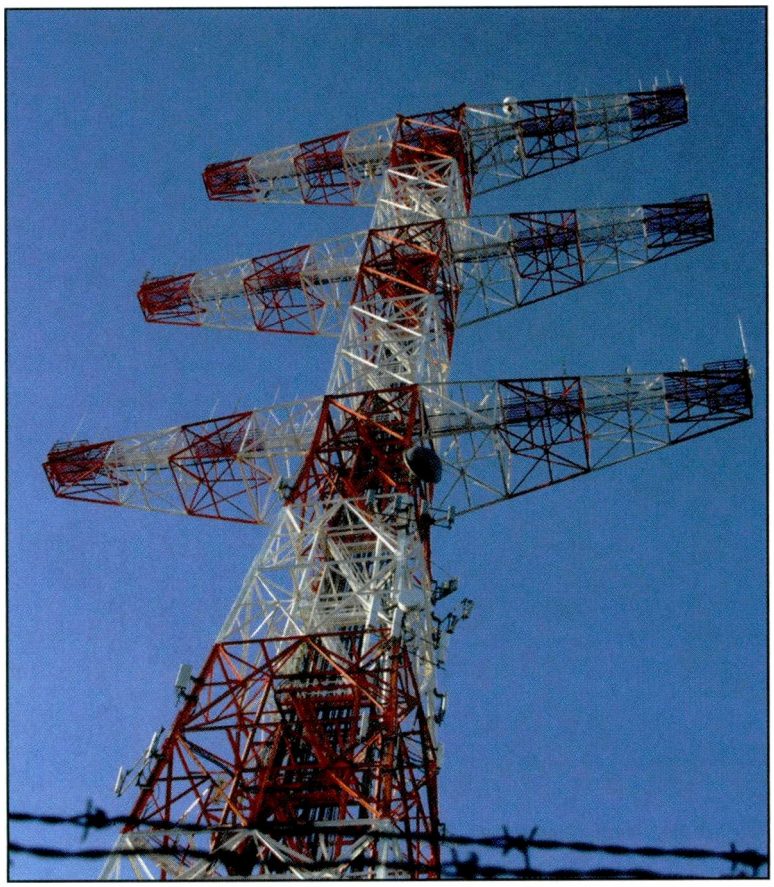

Photo A. The unique Armstrong Tower is designed with three cross arms to maximize horizontal and vertical space for antennas. *(Courtesy of WPC1CAT)*

Photo B. Major Edwin Howard Armstrong, Father of FM *(Courtesy of Wikimedia Commons)*

Photo C. David Sarnoff, who would go on to head RCA, battled Armstrong on the development of FM because of its threat to AM broadcasting.

from the Empire State Building due to both personal and professional conflicts of interest with Sarnoff. So Armstrong purchased land atop the 500-foot Englewood Cliffs in Alpine, New Jersey, near one of his favorite DXpedition spots overlooking the Hudson River, across from his hometown of Yonkers, New York. There he would build a new field laboratory to continue FM development.

Armstrong completed construction of an antenna tower in 1938 at his Alpine site to accommodate experimental FM radio station W2XMN. The "Armstrong Tower" and laboratory building are still standing today.

The self-supporting steel lattice tower measures 400 feet tall with three 150-foot crossbars designed to maximize available vertical and horizontal space for antennas on the tower, making it quite unique. In April of 1938, W2XMN signed on the air for the first time from the new site at 43.7 MHz with a power of 600 watts, but it wasn't until 1941 when the FCC officially set aside 40 channels between 42 to 50 MHz for the FM broadcast band where W2XMN was assigned 42.8 MHz.

Soon the FCC identified the need to allocate more spectrum for FM radio, but the current band was being squeezed by television. So in 1945, after months of deliberation including push-back from Armstrong, the FM broadcast band moved to an expanded 100 channels between 88 and 108 MHz, making old FM radios obsolete by 1948 when low-band FM was terminated.

FM 101: Understanding the Mode

FCC 47 CFR 73.681 defines FM as "a system of modulation where the instantaneous radio frequency varies in proportion to the instantaneous amplitude of the mod-

Photo D. The historic Armstrong site remains an active communications facility today, so public access is restricted with the area secured by a barbed wire-topped fence.

Photo E. Although the old W2XMN building is said to house a small Armstrong museum, there's no regular public access beyond the fence surrounding the site. *(Courtesy of WPC1CAT)*

ulating signal and the instantaneous radio frequency is independent of the frequency of the modulating signal." Let's try to break it down into simpler terms.

Frequency modulation is the imposition of an audio signal on a carrier frequency such that it causes the frequency to vary proportionately. As the audio frequency changes, so does the carrier frequency.

In theory, an RF carrier is frequency modulated by an audio signal such that it causes the carrier frequency to change. This is a major difference between FM and amplitude modulation (AM) where the carrier frequency does not change. In other words, when an AM receiver is tuned to a station on 900 kHz, the received carrier frequency does not vary. When an FM receiver is tuned to a station at 100.1 MHz, although the receiver remains tuned to that frequency, the actual transmission frequency is varying proportionately with the audio frequency.

So, for example, if a 15-kHz tone was used to modulate the 100.1-MHz carrier, then the resulting FM frequency would be 100.115 MHz (100.1 MHz + 15 kHz). An FM receiver tuned to 100.1 MHz would detect the difference between the tuned frequency of 100.1 MHz and the received signal at 100.115 MHz, converting or demodulating that difference back to a 15-kHz tone.

In reality, the implementation of wideband FM is far more complex. Something called the *modulation index* is used with frequency multiplication to improve audio performance and stability. The modulated carrier frequency actually starts out at a lower frequency which is then multiplied until the desired carrier frequency is reached.

The modulation index is the ratio of the frequency deviation to the frequency of the modulating wave. In the earlier example, the carrier frequency deviation from 100.1 to 100.115 MHz is the same as the modulating audio signal of 15 kHz, so the ratio is 1. However this represents only 0.015 percent deviation, a very small number. Now let's frequency modulate 20.02 MHz with the same 15-kHz audio

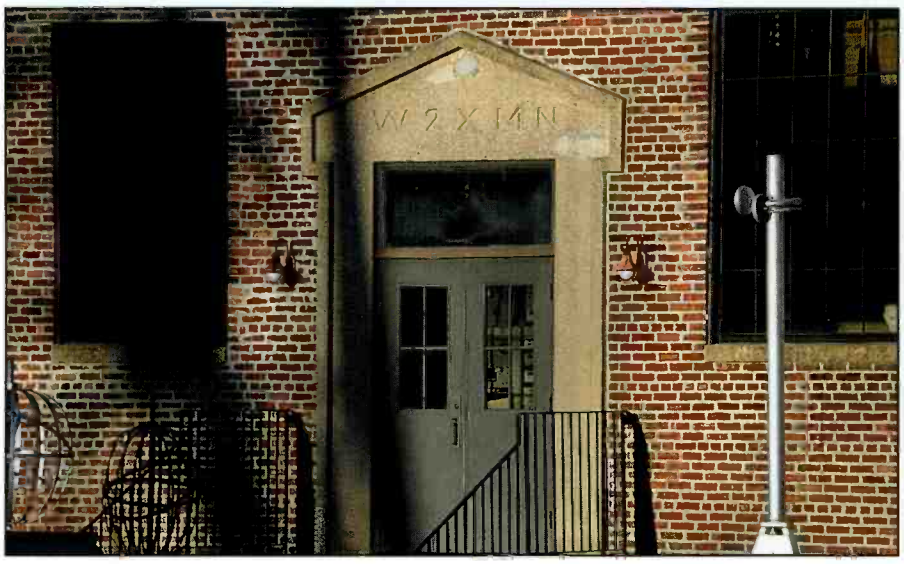

Photo F. The W2XMN callsign is literally *etched in stone* above the front entrance to the Armstrong building. *(Courtesy of WPC1CAT)*

Photo G. The Armstrong Tower stands tall over a nearby neighborhood of million-dollar homes in Alpine, New Jersey. *(Courtesy of WPC1CAT)*

signal, then multiply 20.02 MHz by a modulation index of five which gives us 100.1 MHz. Accordingly the modulation is also multiplied by five resulting in a frequency deviation of 75 kHz so the actual FM signal is now 100.175 MHz. This results in 0.075 percent deviation, still a small number, yet providing significantly more working headroom and improved efficiency.

It's important to note that while the carrier frequency varies when modulated, the amplitude of the FM signal remains constant. Thus a strong signal swamps out any co-channel interference, so only one signal at a time is received. Furthermore most man-made and natural random noise sources are amplitude modulated, so frequency modulation as we all know is immune to noise.

However, white noise or hiss on an FM radio can occur when tuned to a weak signal. A signal must be strong enough to overcome a noise threshold to receive clean audio. Anything below the threshold is like falling off the FM version of the fiscal cliff. The same noise can also be caused by tuning off-frequency.

Using the example of an FM station at 100.1 MHz, if the receiver is tuned off-frequency to 100.09 MHz then the 10-kHz offset is demodulated into noise. Noise caused by frequency drift was a monumental challenge for FM designers, eventually solved by the development of the phase-locked loop.

By the way, 15 kHz is selected for the audio signal in this example because for FM radio that's the maximum audio frequency limit, and 75 kHz is the maximum frequency deviation

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allowed for transmission of the audio information. This also basically explains the 200-kHz spacing between FM channels to prevent adjacent signals from overlapping. Bandwidth above and below the center carrier frequency is also used for multiplexing stereo and subcarrier information including RDS display, SCA channels, and now HD digital.

FM Development Path

The carrier frequency of an FM radio signal is modulated through an exciter. The frequency stability of the earliest FM exciters was difficult to maintain. Mechanical L-C tank circuits were used for frequency control until Armstrong developed a method of applying phase modulation and frequency multipliers to frequency modulate the carrier frequency, which allowed for crystal control of the fundamental frequency prior to multiplication to reduce frequency drift.

This frequency multiplication method is now referred to as indirect FM. The complexity of the circuitry required to perform this task was further reduced by the development of the GE Phasitron vacuum tube which became the standard in the early days for crystal controlled indirect FM exciters. *(**IN DEPTH:** Link to Dave Hershberger, W9GR's, Phasitron Website <http://www.w9gr.com/phasitron.html> for more on the phasitron tube. – WPC1CAT.)*

As technology rapidly evolved with the development of multiplexed FM stereo, the Phasitron soon became obsolete although many monophonic Phasitron transmitters continued to operate into the 1970s.

After the Phasitron, the Serrasoid exciter was the next major technological advancement for indirect FM, using the spikes of a sawtooth wave to carry the audio information. Introduced in the 1940s, the Serrasoid improved distortion specifications, and represented a significant reduction in the size and scope of transmitter circuitry, quickly becoming the new industry standard.

The Serrasoid is considered a predecessor of digital sampling techniques.

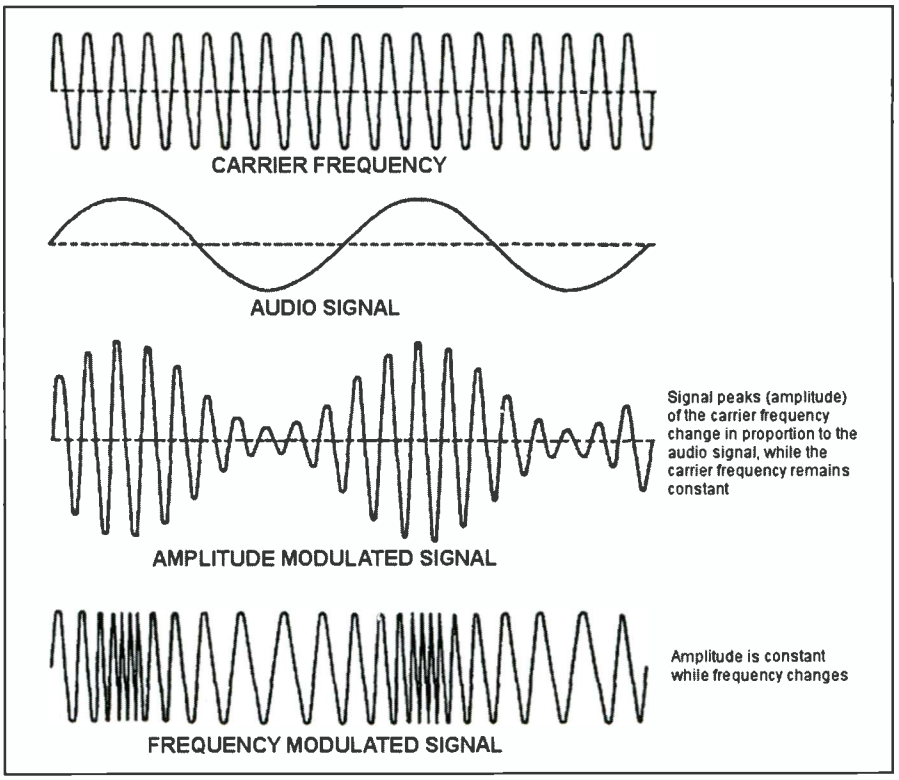

CARRIER FREQUENCY
AUDIO SIGNAL
Signal peaks (amplitude) of the carrier frequency change in proportion to the audio signal, while the carrier frequency remains constant
AMPLITUDE MODULATED SIGNAL
Amplitude is constant while frequency changes
FREQUENCY MODULATED SIGNAL

Photo H. This diagram shows the relationships between a carrier frequency and audio signal with amplitude and frequency modulation. *(Courtesy of WPC1CAT)*

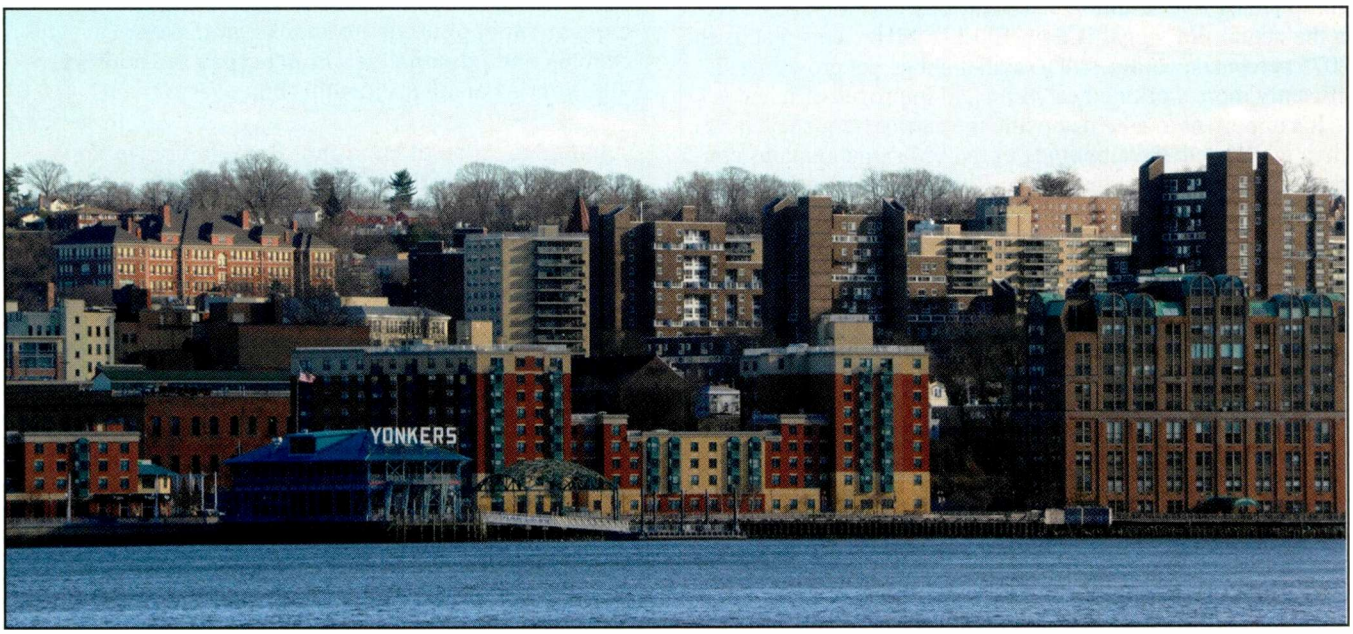


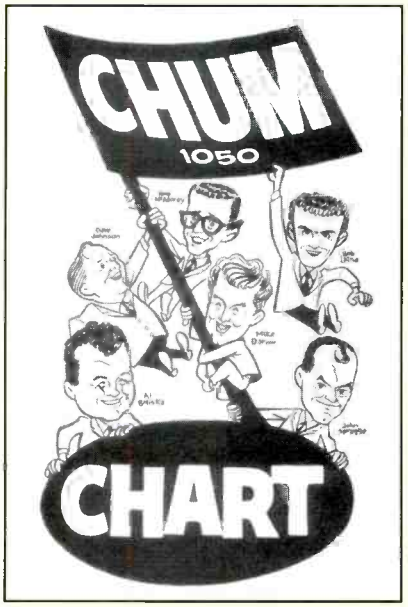
Photo I. Armstrong's hometown of Yonkers, New York can be seen across the Hudson River from the Englewood Cliffs antenna site near Alpine, New Jersey. *(Courtesy of WPC1CAT)*

This Month in Broadcast History

75 Years Ago (1938): The BBC televised the first live coverage of a football (soccer) match in its entirety, England vs. Scotland from Wembley Stadium. Meanwhile, here in the U.S., inventor E.H. Armstrong began testing experimental VHF FM radio station W2XMN on 43.7 MHz with an output of 600 watts from his lattice tower in Alpine, New Jersey. *(**NOTE:** See Broadcast Technology for details, and visit <http://bit.ly/TIEGiH> to see pages of the original W2XMN logbook. – WPC1CAT.)*

50 Years Ago (1963): The soap opera General Hospital premiered on ABC television. *(**WATCH:** A "General Hospital" promo from 1963 at <http://bit.ly/XKGRxH>. – WPC1CAT.)* "I Will Follow Him," by Little Peggy March, <http://bit.ly/X2uxZ1> led Toronto's 1050 CHUM Hit Parade.

25 Years Ago (1988): 104.1 WKIR Jackson, Tennessee personality Dan Baxter lost his job after an April Fools snowy weather forecast caused listeners to panic and got the attention of the Highway Patrol and Civil Defense authorities. *– WPC1CAT*



Fifty years ago this month "I Will Follow Him," by Peggy March led Toronto's CHUM 1050 Hit Parade. *(Internet screen grab)*

However frequency drift remained a problem for FM, and the Serrasoid provided only about 40 dB of stereo separation. A better system was needed to handle the demands of FM stereo and subcarrier multiplexing.

Phase-Locked Loop to Today

The introduction of the phase-locked loop (PLL) was yet another major advancement for FM, improving both transmitter and receiver frequency stability. While the development of PLL circuitry dates back to 1932 with the design of a direct-conversion receiver, the technology was primarily limited to television horizontal and vertical sweep lock applications. Remember adjusting the horizontal and vertical controls of an analog TV to get rid of those black bars sweeping across the picture tube? That was PLL circuitry in action. The introduction of PLL integrated circuits in 1969 made the circuitry easier to implement and more cost effective

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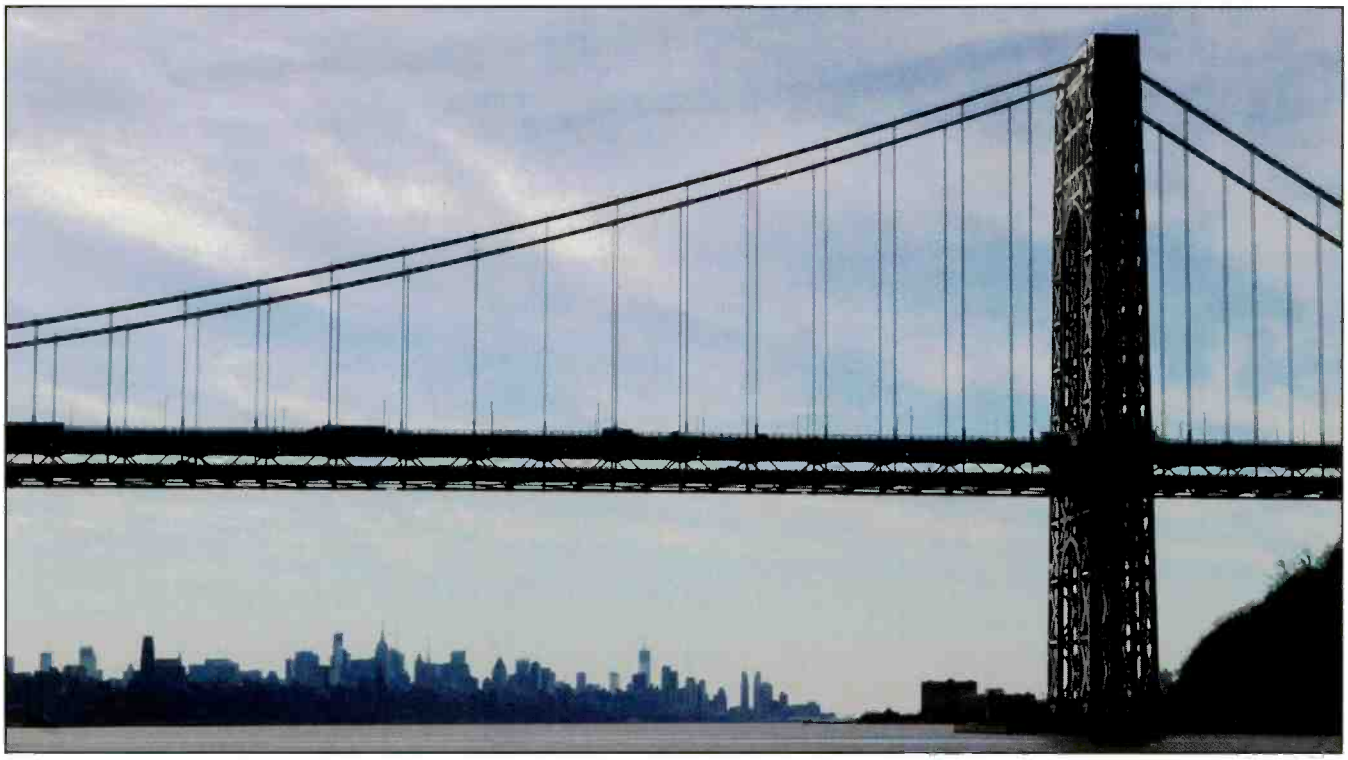

Photo J. From near the Armstrong antenna site, a view of lower Manhattan can be seen from the New Jersey side of the Hudson River beneath the George Washington Bridge.

for RF applications. PLL advancements gave us automatic frequency control (AFC) on FM radios in the 1970's.

Fast forward to today and the development of the high-power, on-carrier phase-locked direct FM exciters. Direct frequency modulation (DFM) inserts the audio information directly to a voltage-controlled oscillator such that the frequency deviation of the oscillator is directly controlled by the modulating signal. Frequency multiplication is still required in the final stages to produce a carrier frequency in the 88 to 108-MHz range and provide an efficient modulation index. But, unlike the indirect FM method that is limited by crystal control, an automatic frequency control loop improves the frequency stability of direct FM while allowing for greater frequency deviation to accommodate FM stereo and multiplexing.

Epilogue

Today the Armstrong Tower continues to be part of an active communications antenna site maintained by CSC Management <http://www.cscmgt.net/history.php> located off Route 9W in Alpine, New Jersey. The building that served as the Armstrong laboratory still has the old experimental FM callsign W2XMN etched in stone above the main entrance. Although part of the building is preserved as an Armstrong museum of sorts, there is essentially no regular public access to this historic building and tower site, which is surrounded by barbed wire fence.

The main driveway is guarded by a security gate and cameras, and a gated side entrance is impassible, blocked by fallen trees and debris. The site is occasionally opened for re-enactments of W2XMN broadcasts in the VHF band to commemorate important anniversaries. WA2XMN is licensed by the FCC to broadcast on 42.8 MHz under a Special Temporary Authority (STA) for such special events. Past events have been simulcast on 89.1 WFDU FM, the voice of Fairleigh Dickinson University, which also transmits from an antenna on the tower. Subscribe to an email reflector at <http://www.wa2xmn.ar88.net> for notification of upcoming broadcasts.

Armstrong was a student and later a faculty member at Columbia University in New York City where much of his original FM research took place. Philosophy Hall on the Columbia campus is recognized by the National Register of Historic Places and designated a National Historic Landmark as the birthplace of FM radio.

A plaque posted outside the labs in 2003 proclaims the landmark designation: "This building possesses national significance in commemorating the history of the United States of America. Edwin H. Armstrong developed a series of advances in wireless communications technology in his second floor laboratory between 1913 and 1954. These contributions, which included FM radio, had an important impact on the history of communications." To learn more about the story of Armstrong at Columbia University, visit <http://bit.ly/XKCpzb>.

Assignment: FM DX

Attempting to explain FM without getting too technical is a challenge. Hopefully you've gained a better understanding of FM, at least conceptually, if your eyes didn't glaze over along the way.

Now your homework assignment is to attempt FM broadcast DXing in honor of Armstrong. Some of the best FM DX conditions occur from late spring into the summer. Tropospheric ducting can propagate loud and clear FM broadcast signals over hundreds of miles. Check out the VHF propagation map at <http://bit.ly/WvC2sj> for an indication of tropo conditions in real time. Also take a look at <http://www.dxmaps.com> for real-time mapping of propagation phenomena, covering everything from E-skip and tropo to auroral QSOs on VHF frequencies. Then be sure to let us know what you're receiving.

– 73 and Good DX! – WPC1CAT